RESEARCH INTO ELECTRONIC MAPS AND AUTOMATIC VEHICLE LOCATION

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ABSTRACT

This paper begins with an overview of possible land-based applications of electronic maps and Automatic Vehicle Location (AVL) systems in the commercial, civil and military sectors. The desireable software and hardware characteristics of these AVL systems are defined. Existing AVL systems are overviewed. A prototype AVL system, named AVL 2000, is being developed and tested at The University of Calgary in order to help define problems and identify solutions, primarily with on-road, land applications. The hardware segment consists of a Trimble 4000S GPS satellite receiver and a MACPLUS micro-computer with a graphics display all mounted in a van. The software segment consists of a control program, map and route data bases, as well as data bases for auxiliary and collected data. A "best route" determination scheme is part of the AVL 2000 prototype system. A learning capability employing artificial intelligence techniques is the important feature of future models of the AVL 2000 system. Experience with the AVL 2000 prototype system is discussed.

INTRODUCTION

The mid 80's marked the "dawn" of Automatic Vehicle Location (AVL) systems; the 1990's will be the decade in which AVL systems will "blossom"; while the year 2000 will mark the beginning of the age of widespread acceptance and usage of AVL systems.

An AVL system allows a land based user to:

(a) position a vehicle using signals from satellites and information from on-board differential positioning devices;
(b) plot the position on a CRT or flat panel display;
(c) call up a digitized-electronic map of the area and see the vehicle's position relative to a desired location(s); and
(d) obtain instructions (visual and audio) using an expert system on how to proceed from the present location to the desired location (Figure 1).

Getting from location A to location B, and then to location C, and so on, in an optimal manner will soon be possible - getting lost may be a thing of the past.

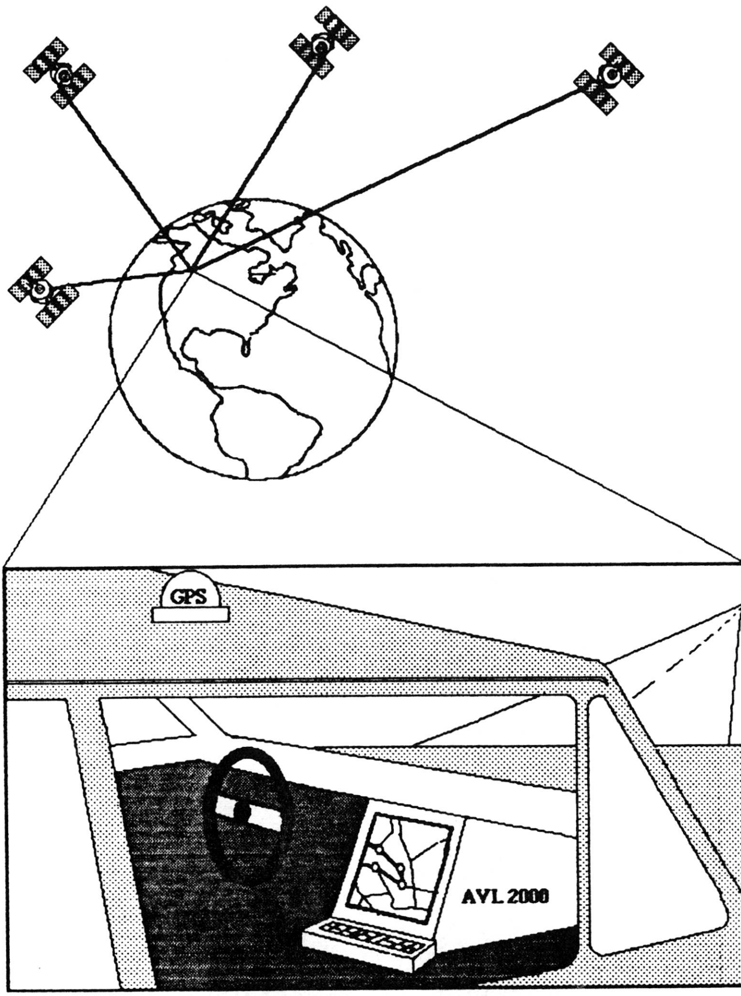

Figure 1. Concept of an Automatic Vehicle Location System

Drivers of police and fire prevention vehicles, ambulances, truck and taxi fleets, courier delivery fleets, farm vehicles, vehicles collecting data (e.g. geophysical), civic vehicle fleets, and even private automobiles will find AVL systems indispensable. The end result will be an enormous saving of time and energy - leaving vast sums of money to help solve other problems in our society.

APPLICATION OF AVL SYSTEMS

AVL systems can find applications in the air, marine and land environments. In this paper we restrict ourselves to use on land. Summarized in Table 1 are applications in four major sectors, namely commercial, civic, private and military. To appreciate how users in these sectors can benefit from an AVL system is best achieved by simply letting one's imagination take over.

Table 1

APPLICATION OF AVL SYSTEMS (LAND-BASED)

C O M M E R C I A L
- delivery and collection fleets
- taxi fleets
- position-based land information gathering vehicles (on and off road)
- automobile associations
- farm trucks and implements

C I V I C
- police and fire prevention vehicles
- waste and refuge removal fleets
- ambulances

P R I V A T E
- passenger car
- off road recreational vehicles

M I L I T A R Y
- on and off road vehicles

The scientific approach to studying the application of AVL systems is to regard the activities of Table 1 as problems in optimization. Leuenberger [1969] suggests that there are at least four distinct optimization problems: (1) estimation; (2) allocation; (3) planning and logistics; and (4) control. In each of the above, some objective function is either minimized or maximized. Let us discuss each of the above within the context of AVL systems and applications.

Estimation concerns itself with the solution of a set of unknown parameters (e.g. AVL coordinates) under the condition that the quadratic form of the errors (e.g. on the observations to satellites) is a minimum. Allocation deals with the distribution of a set of resources (e.g. trucks in a fleet) such that a given amount of work can be done at minimum cost. Planning and logistics involve the placement and movement of resources (vehicles) such that minimum time or cost is incurred. Control is the guidance of an entity (vehicle) along a given path (route). Clearly, optimization is a major part of an AVL system.

AVL systems employ one or more of the above. For example, some application areas, such as those dealing with fleets, are dispatch oriented and, clearly, would involve all four optimization problems. At the other end of the spectrum, a private passenger vehicle would involve only estimation (position) and control (route direction). Nevertheless, the types of problems that need to be solved in AVL systems are clear. This in turn dictates the array of components that must be part of AVL systems.

AVL COMPONENTS AND THEIR FUNCTIONS

AVL systems are clearly an assembly of technologies [Skomal 1981]. These include: (1) positioning systems; (2) a computer-microprocessor; (3) input devices; (4) output devices; (5) map storage devices; and (6) management and computational software (Figure 2).

Positioning systems can include Loran-C, Transit satellite and GPS receivers for point (absolute) positioning; for relative positioning, differential wheel movement devices, and odometer-compass combinations. Point positioning devices can be used alone, or can be integrated with relative positioning devices. They have a symbiotic relationship - when point positions are not available (say due to satellite masking or outages), relative positioning devices are used to interpolate positions. In the case that relative positioning devices have operated alone for some time, their drifts can be corrected - updated by point positioning devices.

Computers and microprocessors are needed to process and send various kinds of data between the multitude of devices. These may be self-contained units in each vehicle, or reside at the central dispatch station. The latter are larger and have more capacity. Typically, self contained computers on board vehicles are small PCs containing limited memory. Microprocessors of comparable size are one order of magnitude lower in price and carry out well-defined, specific functions.

Input devices vary according to what unit we are speaking about. The vehicle unit can have a (i) keyboard-pad; (ii) finger touch control; (iii) transmitter-receiver; or even (iv) voice input. The base unit for dispatch systems can have the following input devices: (i) transmitter-receiver; (ii) radio; (iii) keyboard-pad. Roadside input units usually have an inductive loop buried in the road surface and a transmitter-receiver.

Output devices for the vehicle itself include the following: (i) vector display CRT; (ii) voice synthesizer; (iii) video display; and (iv) a transmitter-receiver. The base unit for dispatch systems has the same units as the vehicle itself plus a radio to transmit and receive information to the vehicles. Roadside output units are the same as input units.

Map storage and management can be self-contained in the vehicle itself and be in the form of an electronic map inside the computer, on a video disc, a photographic map, or special map sheets. Maps can also originate from a control database and access may be direct, thus yielding a true electronic map, or it may be public access through a centrally located terminal.

Software is needed to perform many specialized functions. Some of these include: (i) speech algorithm; (ii) database and display algorithm; (iii) zooming algorithm; (iv) optimized route algorithm; (v) auxiliary information capability; and even (vi) an expert system capability.

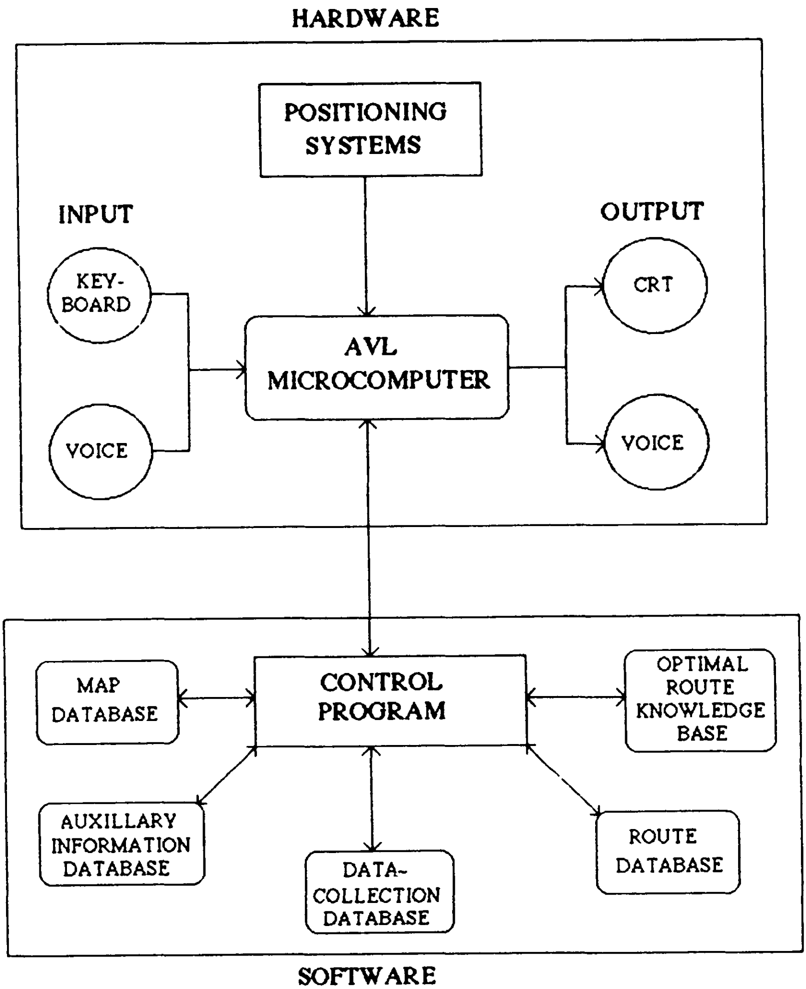

Figure 2. Components of an Automatic Vehicle Location System

EXISTING AND DEVELOPING AVL SYSTEMS

The authors have researched the literature and found that a total of at least 18 AVL systems exist and are under continuous development and improvement (Table 2). This is ample evidence for the statement made earlier that the 1990's will be a period in which AVL systems will blossom. They will be highly specialized and hence aimed at a certain spectrum of the market. No one system will be capable of serving the entire market.

The one component of AVL systems that is more or less a common denominator for on-road applications is the electronic map. Nevertheless, even this component will

EXISTING AND DEVELOPING AVL SYSTEMS	HARDWARE																					
	NAVIGATION			COMPUTER		INPUT FACILITIES									OUTPUT FACILITIES							
						VEHICLE UNIT				BASE UNIT			ROAD		VEHICLE UNIT			BASE UNIT			ROAD	
	OPEN LOOP D.R.	CLOSED LOOP D.R.	GPS SATELLITE SYSTEM	SELF-CONTAINED	LOCATED IN BASE STATION OR ROADSIDE UNIT	KEYBOARD/PAD	FINGER TOUCH CONTROL	TRANSMITTER/ RECEIVER	VOICE INPUT	TRANSMITTER/ RECEIVER	RADIO	KEYBOARD/PAD	INDUCTIVE LOOP	TRANSMITTER/ RECEIVER	VOICE SYNTHESIZER	VIDEO DISPLAY	TRANSMITTER/ RECEIVER	TRANSMITTER/ RECEIVER	VIDEO DISPLAY	RADIO	INDUCTIVE LOOP	TRANSMITTER/ RECEIVER
Etak Navigator		✓		✓		✓										✓						
CARGuide				✓		✓									✓	✓						
Flair	✓	✓			✓	✓		✓		✓	✓	✓						✓	✓	✓		
VDO Citypilot		✓		✓		✓										✓						
Navigator				✓		✓									✓	✓						
Chrysler : CLASS			✓	✓			✓									✓						
Buick Questor			✓	✓																		
Honda : Gyrocator	✓			✓												✓						
Nissan : CUE - X			✓	✓												✓						
Inductive loop based Guidance System					✓	✓		✓					✓	✓		✓					✓	✓
Experimental Systems					✓			✓						✓		✓						✓
Auto - Scout					✓	✓		✓						✓		✓						✓
Wootton Jeffrey				✓		✓									✓							✓
ROUTE - TEL					✓	✓																
Route Systems					✓	✓																
Magnavox	✓		✓		✓	✓	✓	✓		✓	✓					✓	✓	✓	✓	✓		
AVL 2000 (prototype)			✓	✓		✓										✓						
AVL 2000 (1st generation)	✓	✓	✓	✓		✓	✓		✓						✓	✓						

Table 2. Existing and Developing Automatic Vehicle Location Systems

EXISTING AND DEVELOPING AVL SYSTEMS	MAP STORAGE						SOFTWARE					
	SELF-CONTAINED DATABASE				CENTRAL DATABASE							
	ELECTRONIC MAP	VIDEO DISKS	PHOTOGRAPHIC MAPS	MAP SHEETS	ELECTRONIC MAP	PUBLIC ACCESS TO CENTRALLY LOCATED TERMINAL	SPEECH ALGORITHM	DATABASE / DISPLAY MANIPULATION ALGORITHM	ZOOMING ALGORITHM	OPTIMAL ROUTE ALGORITHM	AUXILIARY INFORMATION CAPABILITY	EXPERT SYSTEM ALGORITHM
Etak Navigator	✓							✓	✓			
CARGuide	✓						✓	✓	✓	✓		
Flair					✓			✓	✓		✓	
VDO Citypilot				✓								
Navigator	✓						✓	✓		✓	✓	
Chrysler : CLASS		✓						✓	✓			
Buick Questor	✓							✓				
Honda : Gyrocator			✓									
Nissan : CUE - X												
Inductive loop based Guidance System					✓			✓		✓	✓	
Experimental Systems								✓	✓	✓		
Auto - Scout								✓				
Wootton Jeffrey	✓							✓				
ROUTE - TEL						✓				✓	✓	
Route Systems						✓				✓	✓	
Magnavox					✓			✓		✓		
AVL 2000 (prototype)	✓							✓		✓		
AVL 2000 (1st generation)	✓	✓					✓	✓	✓	✓	✓	✓

Table 2. Existing and Developing Automatic Vehicle Location Systems (continued)

need extensive customizing. This customizing will depend upon the special feature(s) of the particular AVL system. To illustrate this point, witness the AVL 2000 system (Table 2). Two levels of customizing had to be done: the first, occurred in developing the map database itself from a transportation network database, and a second level occurred in establishing the route database so that minimum route calculation could be done in real time in the vehicle.

So called public-based AVL systems are illustrated by the Routes System (Table 2). Note, the characteristics and components of this system are quite different from, say, the Buick Questor system which is essentially self-contained.

THE AVL 2000 SYSTEM

The AVL 2000 system is an in-vehicle real-time system which utilizes an integrated positioning system to, first, locate a moving vehicle and then have its position superimposed on a digital route map displayed on a CRT. One of the main features of the AVL 2000 system is a real-time optimal route selector [e.g., Dijkstra 1959], that is, the determination of the "best" route between the starting point and the destination point. The criteria for "best" route depends on the type of application [Karimi et al. 1987].

The first phase in the development of the AVL 2000 system was to assemble a prototype from existing hardware. The main challenge faced in developing the prototype system was system integration, which included interfacing the hardware components and developing software. The prototype is a microcomputer-based AVL system and an algorithmic approach was used in its software development. Illustrated in Figure 3(a) is the AVL 2000 system prototype configuration.

The first generation system is to be a product model. The design includes the integration of a GPS point positioning receiver and dead-reckoning device. An integrated positioning system would provide continuous and reliable positioning. Figure 3(b) shows the first generation AVL 2000 system configuration.

The second generation of the AVL 2000 system is conceived as being an AVL system which will use the latest advancement in both hardware and software components. As such it will be a microprocessor-based AVL system, and its software will be based on heuristic principles instead of being entirely algorithmic. It will also be an intelligent-customized AVL system in which the state-of-the-art design and architecture will be used; namely it will be VLSI based. Its configuration is shown in Figure 3(c).

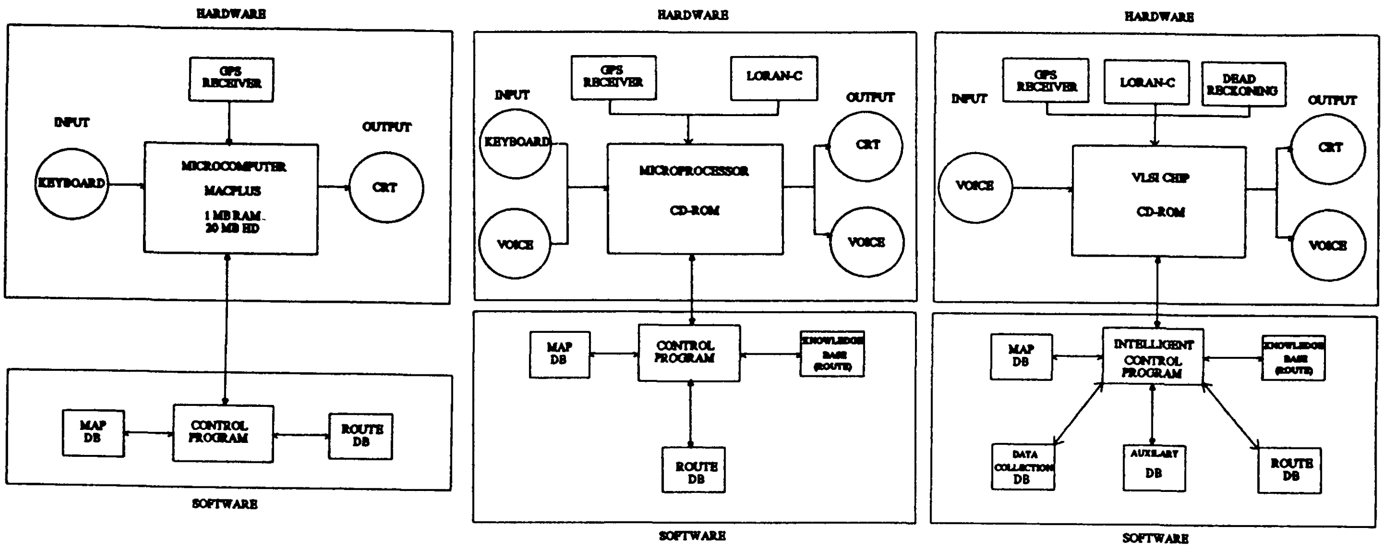

Figure 3. AVL 2000 Systems

PRACTICAL EXPERIENCE WITH AVL 2000 (PROTOTYPE)

The aim of this research was to build a prototype system as quickly as possible and get some practical experience at the earliest possible stage of the research. This we have done and discussed below are some of the problems encountered and solutions we have formulated. Experience has been gained with the hardware, software and, as important, with the digital map information.

Interfacing of the Trimble 4000S GPS receiver and MACPLUS was readily accomplished via a standard serial port (RS232). This configuration was then mounted in a van with power supplied from a 12 volt battery and from the vehicle using an alternator.

Digital-electronic maps for the Calgary test area are not available. Two sources of information were used to create a customized electronic map for AVL purposes. The first was a coordinate file of all road intersections in the Alberta Transport Link-Node Network [Yeung 1986]. Auxiliary information included: class of road; speed; length of link; etc. The second set of information was a coordinate file of 72 municipal polygons of the Province of Alberta. This latter information was needed in order to divide the province into manageable parts for the real-time operation of the minimum route algorithm.

To customize the data for the AVL prototype, the boundary and link files were merged. Each link was checked against each polygon to determine if it was within that polygon. This was done by first checking the maximum and minimum limits of the polygon, then using a point in polygon algorithm (number of times link crosses polygon boundary) to exactly determine if the link is within the polygon. The polygon ID was then attached to the link. If the link was within two polygons, an additional node was placed at the boundary to split the link so that no link is within two polygons. The large-merged data file was then split into one data file for each polygon to enable faster access.

Displayed in Figure 4 are the primary routes contained in one of the 72 municipal district polygons. Contained therein is the City of Calgary. Also shown in the figure is the best route selected between beginning and destination points.

Shown in Figure 5 is a hard copy of the CRT image of the AVL 2000 system. It is a zoom-view of a portion of the optimum route. Note a major turn is indicated and notice is given to the fact that the driver has left the "best" route.

Several field tests are underway with the AVL 2000 system.

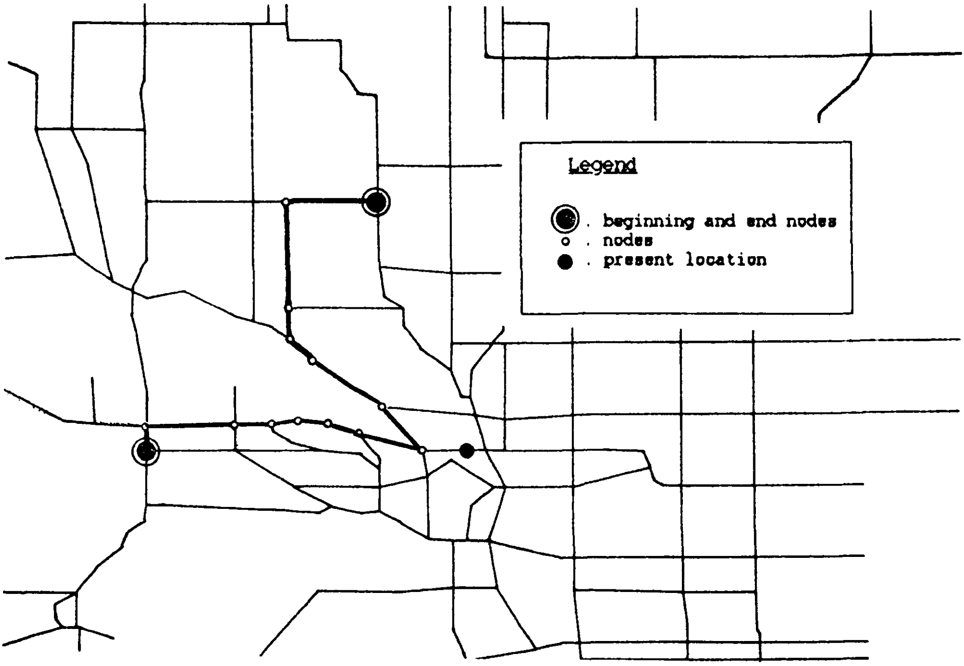

Figure 4. Electronic Map of a Municipal Polygon Containing Calgary

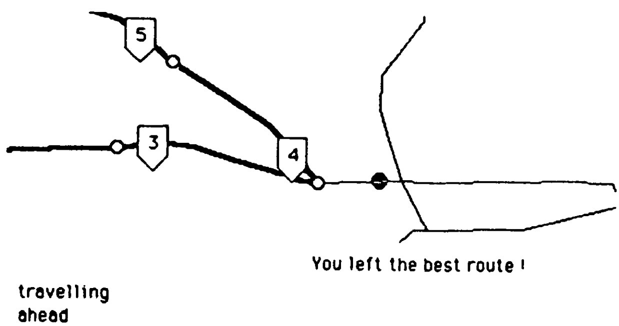

Figure 5. Zoom-View of a Portion of the Best Route

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